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SEEDBED DENSITY AND PINE SEEDLING GRADES IN CALIFORNIA NURSERIES

By
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ABSTRACT: Lower seedbed densities for pine planting stock in California produced larger, more vigorous seedlings. Both 1-0 stock from a Placerville nursery and 2-0 stock from a Mt. Shasta nursery increased in average stem diameter and fresh weight as the numbers of plants per square foot of seedbed were reduced from 60 to 10. Two seasons after hand planting, field survival of Mt. Shasta stock grown at 50 per square foot was 62 percent; that of stock grown at 10 per square foot was 83 percent. After machine planting with comparable stock, survival was 79 and 92 percent.

The increased use of seedlings (1-0 and 2-0) instead of transplants in reforestation programs in California has reduced unit costs and speeded production. But the practice has introduced new problems of quality control (Buck 1959). Density of sowing is of great importance where seedling stock is grown. In transplant beds, the trees finish their nursery growth at uniform spacing. But in seedling beds, seeding method largely regulates density.

This paper reports on studies relating seedbed density to seedling quality at the Mt. Shasta and Placerville nurseries of the U.S. Forest Service.

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More than 30 years ago, the emphasis was on transplants, with 1-1 or even 1-1-1 preferred. Seedlings were not considered hardy enough because root pruning in place was not common. The usual practice was to sow heavily, then cull and space during transplanting. Some trees appeared to have superior quality for planting, and these Show (1930) termed "first quality." But in recognizing the need for a "quantitative standard of quality," he stressed two criteria: (a) total fresh weight, which he called "perhaps the best single index of development"; and (b) the ratio of fresh weights of tops to roots of trees severed at ground line. A quarter century later, Corson and Fowells (1952) substituted stem diameter as the major criterion for grading stock. They recommended planting 1-1 ponderosa stock with a 0.11-inch or larger stem diameter.

The aim of the study reported here was to clarify these grading criteria under current, revised cultural practices at two nurseries with different climates. We wanted to learn how the density of plants in the seedbed affected the height, weight, stem diameter, and top/root (T/R) ratios of 1-0 and 2-0 seedling. We also tested the field survival of outplanted 2-0 stock representative of the different seedbed densities.

Materials and Methods

The same procedure was followed at both the Mt. Shasta nursery, in the Sierra-Cascade mountains at 3,300 feet, and the Placerville nursery, on the west slope of the central Sierra Nevada at 2,700 feet. Seeds from several seed zones (Fowells 1946) were arranged in four replications with the seedbed densities randomized within blocks.

The Placerville nursery tests included 1-0 ponderosa, Jeffrey, and sugar pine stock. At the Mt. Shasta nursery, 2-0 Jeffrey pine and ponderosa pine stock were grown.

Each seed-source bed was divided into 4- by 4-foot density plots. The seedbeds were all drill-sown with stratified seed in spring at a rate calculated to yield at least 60 seedlings per square foot. After germination, plots were hand-thinned to densities of 10, 20, 30, 40, 50, or 60 per square foot. The test beds underwent normal cultural practice at each nursery. Following a standard practice of the Mt. Shasta nursery, the roots of 2-0 stock were pruned to 8 inches in April of the second growing season. But no root pruning was done on the Placerville stock, either before or after lifting.

At the time of lifting, 20 sample seedlings were selected at random from each replication and taken to our laboratory in Berkeley. For each seedling stem, we measured its diameter at ground line and its height from ground line to shoot apex. We then cut each seedling at the ground line and weighed its tops and roots.

The Mt. Shasta stock also provided material for a large-scale outplanting test. We chose at random samples of 100 trees from each density replication and outplanted them immediately on prepared sites

near Mt. Shasta. Each seed source having 5 x 4 or 20 replications supplied 2,000 test trees. Half of each sample was machine-planted and the other half hand-planted. Survival was checked after the first and second seasons.

Results

Analysis of variance was used to evaluate the effect of seedbed density upon seedling dimensions, and regression analysis to obtain quantitative expressions for the effects. Results were viewed primarily for evidence of consistent trends over the range of densities used in the tests. At Placerville, actual and assigned densities of 1-0 stock agreed well. At Mt. Shasta, the 2-0 stock, having spent twice as long in beds, had slightly greater losses. Although actual seedbed densities varied somewhat from those planned, this difference did not affect our conclusions.

Placerville nursery.--The Placerville study was held in 1959 and 1960. In 1960 the ponderosa pine samples were accidentally lifted with production-run stock; therefore, we have data only for 1 year for ponderosa pine, but 2 years for Jeffrey and sugar pine.

Top heights generally averaged 3.5 to 4.0 inches throughout, and the ratios of top weight over root weight remained fairly low (1.0 to 1.6) (table 1). Except for the sugar pine stock, the average total weights of sample seedlings declined noticeably as seedbed density increased. Moreover, stem diameter reflected quite closely the trends in weight.

If 0.11 were the minimum acceptable stem diameter, only the ponderosa and Jeffrey pines grown at 10 to 20 per square foot would have had reasonably low cull percentages (below 25 percent). At 40 per square foot, nearly half the ponderosa pine, more than 60 percent of the Jeffrey pine, and all of the sugar pine stock would have been culled. It may be necessary to grow 2-0 sugar pine stock or to use a smaller minimum stem diameter, for example, 0.08 inch. On the other hand, another study has indicated that the stock was smaller than the nursery could produce.[2/]

The effect of different growing conditions at the same nursery in different years is shown by the Jeffrey and sugar pine stock (table 2). Both species averaged greater seedling weight in 1960 than in 1959, although average stem diameter was about the same. In general, plants were taller in 1960, but the decreased size and top/root ratio associated with greater bed density were still apparent. Cull percentages for Jeffrey pine were quite similar for the 2 years tested.

2/ Baron, F. J., and Fowler, Carl W. Sugar pine seedling size--a reflection of seed handling? 1962. (Unpublished report on file at Pacific Southwest Forest & Range Expt. Sta., U.S. Forest Serv., Berkeley, Calif.)

Mt. Shasta nursery.--Top heights varied irregularly with seedbed density (table 3). In fact, the 2-year-old seedlings averaged only slightly taller than the 1-year-old stock from Placerville. The top/root ratio also varied irregularly, generally averaging higher than at Placerville (1.7 to 2.3).

Total seedling weight from all sources decreased markedly as seedbed density increased. In some cases, plants grown at 20 per square foot weighed nearly twice as much as those grown at 50 per square foot.

As at Placerville, seedling weight and stem diameter showed parallel responses to changes in seedbed density. Regression analysis of the ponderosa pine data showed stem diameter decreased 0.014 inches for each increase in density of 10 seedlings per square foot (fig. 1). The Jeffrey pine diameter decreased only 0.011 inches--a small but significant difference.

The Mt. Shasta stock was consistently heavier than that from Placerville, had greater average stem diameters, and fewer "culls" (below 0.11 inches). The lower cull percentages also resulted from subjective grading of the stock made before we obtained samples for measurement. During lifting and packing of more than 58,000 seedlings, about 3,000--those obviously damaged or too small to handle--were tallied and discarded. A small but consistent increase in the proportion of such seedlings accompanied increases in seedbed density (table 4). Considering both nursery grading and stem diameter, seedbed density of 40 per square foot yielded the most "plantable" trees per unit area. Increases in the total numbers of plants per square foot were offset by increased cull percentages.

Field performance.--Field survival of the Mt. Shasta stock, based on 10,000 trees, decreased as seedbed density increased (table 5). Losses after two seasons in the field roughly paralleled the trends for cull rates as a function of seedbed density. The internal consistency of the data is shown by similar trends for all five sources of seed and both methods of planting. Mortality was consistently higher in the hand-planted plots than the machine-planted plots.

Heights of the planted trees were measured when the survival was checked. The decreased height associated with increased seedbed density shown by the laboratory measurements persisted in the field measurements (table 6). The trees grew little or not at all during the first season after planting; they actually averaged shorter, perhaps because they were planted deeper than in the nursery. The average height of machine-planted trees during the first season was less than that for hand-planted trees, and machine planting seemed to reduce the range of heights. This result indicated a deeper and more uniform placement of the trees by machine than by hand planting.

Little or no evidence of browsing by deer was noted the first year, but second-season height growth was rendered meaningless by deer damage.

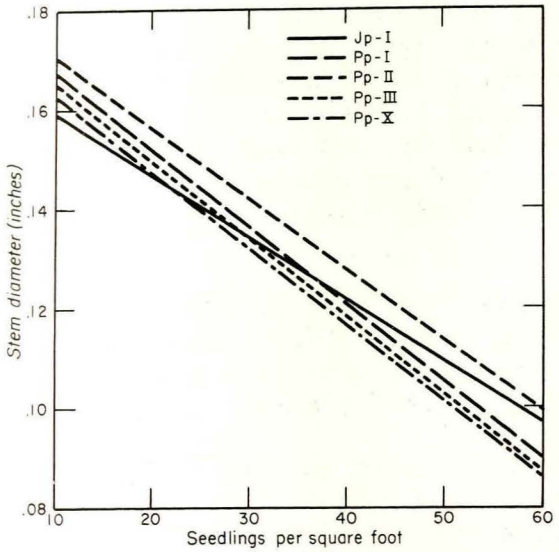

Figure 1.--Regression of stem diameter on seedbed density for 2-0 Jeffrey and ponderosa pine grown at Mt. Shasta nursery from five sources of seed (200 seedlings each). Decrease in stem diameter (0.001 inch) for each density increase of 10 seedlings per square foot:

Jeffrey pine,	Zone I;	-11.4 *
ponderosa pine,	Zone I;	-13.7 *
ponderosa pine,	Zone II;	-13.6 *
ponderosa pine,	Zone III;	-13.9 *
ponderosa pine,	Zone X;	-14.3 *

*significant difference; 5 percent level.

Discussion and Conclusions

Nursery practice relies heavily on rules of thumb. These rules may get the job done, but they provide few clues to explain unsatisfactory performance. Quality control in a production line needs readily measurable, tangible characteristics. The trick is to select the right characteristic.

The most obvious part of a seedling to measure is top height. But we found that height was too variable to provide a convenient measure for comparing different lots of seedlings. The reason is not known, but this variability probably reflects irregular incidence of top-damage from weather, insects, or disease.

Furthermore, this variability carries over into the ratio of top/root weight, which theoretically is a measure of plant "balance" (Show 1930). The T/R values in our samples were relatively low, and we found little evidence for consistent changes in T/R ratio associated with different seedbed densities. Thus, T/R ratios seem to have limited use in quality control--especially since they vary widely, are costly to measure, and destroy the sample plants. Wakeley (1954) and Stoeckler and Jones (1957) have voiced similar objections.

In contrast, seedbed density was associated with consistent patterns in total seedling weight and stem diameter measurements. Such measurements have also proved useful in comparing seedlings elsewhere (Clark and Phares 1961).

Results from the Mt. Shasta trial showed the effectiveness of grading by stem diameter. We noted that 40 plants per square foot was the highest density for which the proportion of "culls" (plants less than 0.11 inch in diameter) did not rise materially above 20 percent. Both Stoeckler and Jones (1957) and Wakeley (1954) consider 20 percent an acceptable

proportion of culls in normal operation of nurseries. In field tests, seedlings from beds of this density performed best; the second-season tally of 10,000 outplanted trees showed that survival averaged below 75 percent for stock grown at densities higher than 40 per square feet. Show (1930) recommended sowing ponderosa, Jeffrey, and sugar pines at 160 per square foot for 1-0 stock, and 60 to 70 per square foot for 2-0 stock. But this study suggests that a much lower number may be desirable to balance productivity and quality.

What factors affect seedbed productivity? Wakeley (1954) suggested that a given area of bed space could produce a fixed amount of plant material. Increasing the sowing rate merely puts this material on more stems and increases the proportion of small plants.

High sowing rates mean an inefficient use of the available seed supply. That is, more seeds are needed to yield a given number of usable seedlings. Because seeds are usually in short supply, this waste is an increasingly important aspect of nursery operation. If seedbed density determines seedling quality, we need to develop more reliable methods of estimating germination in the nursery. At present the unpredictability of germination often leads to oversowing the beds.

Another problem in high-density seedbeds is the greater crowding and interlacing of roots, which become highly susceptible to damage during lifting and separation of the plants. This tendency was indicated at Mt. Shasta, where we noted a slight upward trend in T/R ratio with increased density. Root damage occurs only irregularly, but it contributes to variability in T/R ratio as a function of seedbed density. Root damage, however, should not be a major problem if plants are carefully lifted.

The pruning of roots after a plant is lifted is a separate problem, especially in the larger stock. Limstrom et al. (1955) found that survival of yellow poplar stock increased as stem diameter increased to a certain size, then decreased. They felt that root pruning adversely affected the larger plants. Although stem diameter was the best single criterion of stock quality in their study, it had to be combined with data on root length.

At best, the grades assigned to planting stock are relative values. The severity of one planting site may preclude the use of some grades that would survive well on another site. A planting program often is geared to average conditions, but the current trend is to defer planting on severe sites. Our plantation at Mt. Shasta was on an average or better site. Although the trees apparently were not subjected to extreme drought or heat, stock of all sources grown at the higher seedbed densities showed a noticeable decline in survival. This decline in turn was related to differences in average stem diameter. But separate grading criteria may be needed for different nurseries. For example, the 0.11-inch minimum diameter may not be realistic for Placerville 1-0 stock although it effectively predicted survival of the 2-0 stock from Mt. Shasta.

Physiological grades were not evaluated here in this study, but there is evidence that root regenerating potential (RRP) can be reasonably predicted from concurrent weather data at each nursery (Stone et al. 1963).

Greater uniformity of stock is possible through increased standardization of cultural practices like use of fertilizers, fumigation of the soil, watering schedules, and seed handling. Standardized practices can reduce the influence of uncontrolled variables to a point where the planting stock is "tailor-made" and little need exists for precise measurements for grading.

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Table 1.--Seedling dimensions, 1959 Placerville 1-0 stock, by species and seedbed density[1/]

Item	Seedbed density (seedlings per square foot)			
	10	20	30	40
Height of top, in.:				
Sugar pine	4.0	3.7	3.8	3.8
Jeffrey pine	3.6	3.4	3.4	3.4
Ponderosa pine	4.8	4.2	4.3	4.2
Stem diameter,[2/] in.:				
Sugar pine	.098	.090	.084	.087
Jeffrey pine	.133	.119	.106	.102
Ponderosa pine	.143	.117	.108	.104
Total weight of seedling, gm.:				
Sugar pine	3.19	2.94	2.74	3.07
Jeffrey pine	6.73	5.25	4.18	4.00
Ponderosa pine	9.45	8.17	5.08	4.28
Top/root weight (T/R):				
Sugar pine	1.61	1.30	1.31	1.11
Jeffrey pine	1.22	1.16	1.11	1.06
Ponderosa pine	1.27	1.21	1.20	1.20
Cull,[3/] percent:				
Sugar pine	100	100	100	100
Jeffrey pine	6.8	23.5	42.5	62.0
Ponderosa pine	2.2	18.9	43.7	48.8

[1/] Averages of four samples of 20 seedlings each.

[2/] .004 inch was a significant difference at the 5 percent level.

[3/] Less than 0.11 inch diameter.

Table 2.--Dimensions of seedlings from specified seedbed densities, Placerville 1-0 stock (1959-1960)

Seedbed density (seedlings/ sq. ft.)	Stem diameter		Total weight		Height		T/R		Cull	
	1959	1960	1959	1960	1959	1960	1959	1960	1959	1960
	Inches		Grams		Inches				Percent	
JEFFREY PINE										
10	.133	--	6.74	--	3.57	--	1.22	--	6.8	--
20	.119	.115	5.25	6.71	3.44	4.62	1.16	1.05	23.5	25.0
30	.106	.109	4.18	6.06	3.45	4.63	1.11	.96	42.5	37.5
40	.102	.102	4.00	5.22	3.38	3.98	1.06	.97	62.0	60.0
50	--	.100	--	5.00	--	4.21	--	1.00	--	57.5
60	--	.098	--	4.80	--	4.42	--	.96	--	70.0
Average, 20-40	.109	.109	4.48	6.00	3.42	4.41	1.11	.99	42.7	40.8
SUGAR PINE										
10	.098	--	3.19	--	3.95	--	1.61	--	--	--
20	.090	.087	2.94	3.41	3.72	3.79	1.30	1.46	--	--
30	.088	.091	2.83	3.86	3.83	4.45	1.31	1.23	--	--
40	.084	.090	2.76	3.83	3.85	4.64	1.11	1.22	--	--
50	--	--	--	--	--	--	--	--	--	--
60	--	--	--	--	--	--	--	--	--	--
Average, 20-40	.087	.089	2.88	3.70	3.80	4.29	1.24	1.30	--	--

Table 3.--Seedling dimensions, Mt. Shasta 2-0 stock, by seed source and seedbed density[1/]

Item	Seedbed density (seedlings per square foot)			
	20	30	40	50
Stem diameter, in.:				
Jeffrey I[2/]	.150	.136	.119	.121
Ponderosa I	.151	.125	.125	.096
Ponderosa II	.161	.141	.134	.121
Ponderosa III	.142	.133	.126	.112
Ponderosa X	.150	.129	.126	.104
All	.151	.134	.126	.108
Seedling weight, gm.:				
Jeffrey I	10.53	8.20	6.78	6.35
Ponderosa I	11.12	7.63	7.37	3.87
Ponderosa II	11.77	8.78	7.97	6.77
Ponderosa III	10.82	8.70	7.56	5.90
Ponderosa X	10.42	7.34	7.03	4.59
All	10.90	8.34	7.40	5.16
Top/root weight:				
Jeffrey I	1.71	1.72	1.81	1.84
Ponderosa I	1.84	1.87	1.97	2.04
Ponderosa II	2.06	2.29	2.19	2.02
Ponderosa III	1.92	1.93	1.87	1.95
Ponderosa X	1.99	2.05	2.03	1.99
All	1.89	1.97	1.96	1.98
Height of top, in.:				
Jeffrey I[2/]	4.63	4.46	4.04	4.57
Ponderosa I	4.89	4.35	4.38	3.49
Ponderosa II	4.86	4.38	4.30	3.92
Ponderosa III	4.45	4.26	4.03	4.01
Ponderosa X	4.63	4.17	4.17	3.78
All	4.75	4.32	4.18	3.87

[1/] Averages of four samples of 10 seedlings each.

[2/] Seed zones as delineated by Fowells (1946).

Table 4.--Cull percent based on two different criteria, Mt. Shasta 2-0 stock

Seed source	Seedbed density classes			
	20	30	40	50
CULL PERCENT (NURSERY GRADED)				
Jeffrey pine I	2.6	3.2	4.7	6.9
Ponderosa pine I	1.8	3.2	3.2	7.2
Ponderosa pine II	3.4	3.3	3.8	7.2
Ponderosa pine III	2.1	2.2	3.3	4.0
Ponderosa pine X	3.3	6.1	5.9	9.4
All	2.6	3.4	4.1	7.9
CULL PERCENT (STEM DIAMETER LESS THAN 0.11 INCH)				
Jeffrey pine I	5.0	14.3	28.0	20.0
Ponderosa pine I	4.0	20.0	15.0	73.3
Ponderosa pine II	7.5	11.7	20.0	33.3
Ponderosa pine III	7.5	17.8	24.0	30.0
Ponderosa pine IV	5.0	22.0	33.3	60.0
All	5.7	16.7	23.4	50.1
NUMBER OF PLANTABLE TREES PER SQ. FT.[1/]				
All zones	19	25	31	24

[1/] Stem diameter 0.11 inch and larger; roots not mutilated.

Table 5.--Survival of 2-0 pine lifted from Mt. Shasta nursery, two seasons after outplanting, by planting method

Planting method	Seed zone	Seedlings per square foot			
		20	30	40	50
		Percent			
Machine planted:					
Jeffrey pine	I	91.37	87.58	76.19	69.10
Ponderosa pine	I	91.26	89.47	87.29	82.55
Ponderosa pine	II	91.05	85.59	85.26	81.69
Ponderosa pine	III	95.38	88.88	86.70	96.00
Ponderosa pine	X	91.65	86.68	82.02	75.91
All	--	92.03	87.62	85.50	78.68
Hand planted:					
Jeffrey pine	I	77.40	77.19	62.09	74.10
Ponderosa pine	I	88.27	83.39	77.40	63.29
Ponderosa pine	II	86.17	72.95	66.47	55.98
Ponderosa pine	III	81.57	81.34	73.57	64.65
Ponderosa pine	X	81.93	75.64	84.10	59.42
All	--	82.92	77.98	71.22	61.80
Both methods:					
All zones	--	87.40	82.81	77.35	70.30

Table 6.--Top heights of surviving seedlings after one field season, by seedbed density[1/]

Species	Zone	Seedlings per square foot			
		20	30	40	50
		Inches			
Machine planted:					
Jeffrey pine	I	3.63	3.35	3.01	3.18
Ponderosa pine	I	3.95	3.66	3.12	2.84
Ponderosa pine	II	4.05	3.43	3.72	3.28
Ponderosa pine	III	3.98	3.34	3.21	3.68
Ponderosa pine	X	3.98	3.44	3.51	3.04
All	--	3.88	3.41	3.32	3.11
Hand planted:					
Jeffrey pine	I	3.74	3.69	2.95	3.08
Ponderosa pine	I	4.40	3.58	3.77	2.59
Ponderosa pine	II	4.58	3.25	3.53	2.76
Ponderosa pine	III	3.62	3.53	3.18	2.70
Ponderosa pine	X	3.98	3.61	3.86	2.96
All	--	4.06	3.55	3.41	2.85

[1/] Basis: 1,000 seedlings per seed zone in each method of planting.